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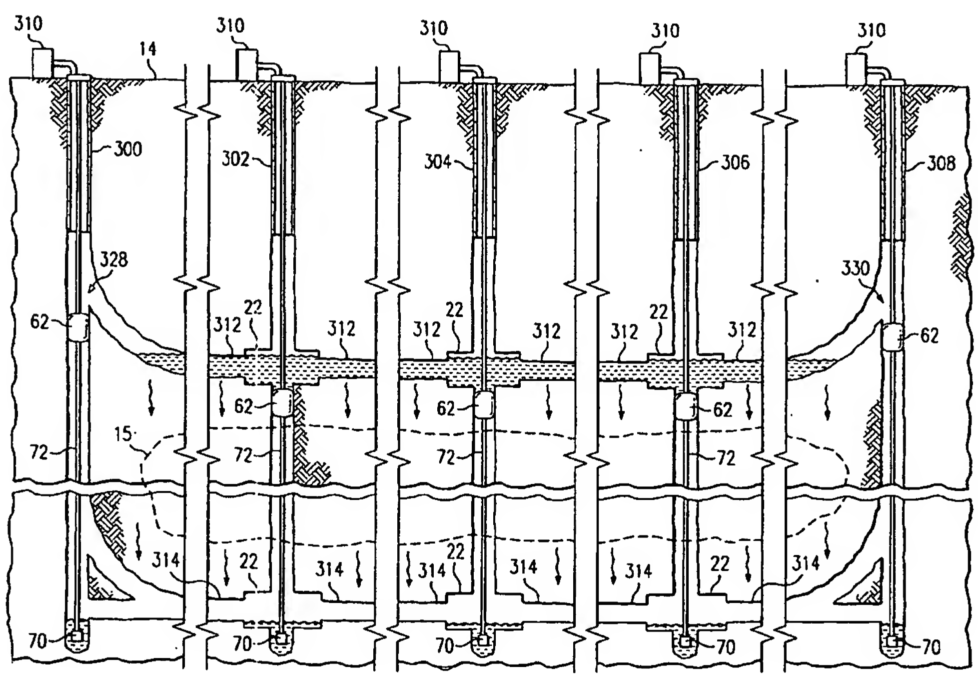
(54) Title: METHOD AND SYSTEM FOR UNDERGROUND TREATMENT OF MATERIALS



(57) Abstract: A method for underground treatment of subsurface materials comprises an injection pattern and a recovery pattern comprising lateral bores extending from a main bore. The recovery pattern may overlay or be horizontally offset with respect to the injection pattern. Packers and valves may be incorporated within the patterns.

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METHOD AND SYSTEM FOR UNDERGROUND TREATMENT OF MATERIALS

TECHNICAL FIELD OF THE INVENTION

This invention relates generally to the field of subsurface drilling methods and systems, and more particularly to a method and system for underground treatment of materials.

BACKGROUND OF THE INVENTION

The use of underground well bores to access and recover subsurface resources is well-known. For example, water, oil, gas and other hydrocarbons as well as other underground resources may be recovered by drilling from the surface to an underground formation containing the resource and producing the resource through the well bore to the surface.

Underground well bores may be used in conjunction with each other to inject a treatment solution and recover a byproduct. For example, precious metals may be mined by injecting a treatment solution into a deposit and recovering the solution plus dissolved precious minerals. The precious mineral is then recovered from the mixture at the surface. Also, heavy oil may be recovered from a tar sand or other zone by injecting steam into a first well and recovering oil pushed by the steam to a second well. In addition to recovering resources, injection and recovery wells may be used to recover underground contaminants posing a danger to the environment.

SUMMARY OF THE INVENTION

The present invention provides a method and system for underground treatment of materials that substantially

reduces or eliminates problems associated with previous methods and systems. A method for underground treatment of subsurface materials comprises providing an injection pattern and a recovery pattern, the injection pattern and the recovery pattern located proximate to a subsurface treatment zone and at least one of the injection pattern and the recovery pattern comprising a plurality of lateral bores extending from a main bore. A treatment solution is injected through the injection pattern and recovered through the recovery pattern.

In a particular embodiment, a pinnate or other suitable pattern operable to access a large subsurface region may be used to inject and/or recover materials underground. In another embodiment, intersection or cooperating patterns may be used to collect, store, and/or process materials underground. In still another embodiment, cavities and horizontal bores are used to create connection points to control and/or regulate the flow of fluids, gases, and other materials underground.

Technical advantages of one or more embodiments of the present invention include providing an improved method and system for underground treatment of materials. In particular, underground resources, contaminants or other materials may be accessed through a pinnate or other access pattern having a large and uniform coverage area to allow underground processing of the materials. As a result, underground materials may be efficiently processed or treated within a formation containing the materials, thus minimizing the need for surface removal and treatment.

Another technical advantage of one or more embodiments of the present invention includes providing an improved method and system for solution mining of underground resources. In particular, the agent or the

solution may be injected through a pinnate pattern with a large coverage area to recover a large volume of a resource with minimal drilling and production cost.

Still another technical advantage of one or more embodiments of the present invention includes providing an improved method and system for treating underground contaminants. In particular, underground contaminants may be neutralized by saturation of a treatment solution over a large area of the contaminated zone or driven in large volume between injection and collection patterns. In addition, vertical plumes of contamination may be contained and treated by a plurality of vertical or other pinnate injection and recovery patterns.

Yet another technical advantage of one or more embodiments of the present invention includes providing an underground circuit for processing materials. In particular, materials may be injected through patterns into the ground, pumped within the underground patterns and percolated through target zones between the patterns to process the materials underground without removal to the surface. In addition, connection points between underground zones, bores, and/or patterns are created with cavities and horizontal bores to control and regulate fluid and gas flows and processing. Accordingly, processing costs and equipment are reduced.

Various embodiments of the present invention may include some, all, or none of these and other described technical advantages. In addition, other technical advantages of the present invention may be readily apparent to one skilled in the art from the following figures, description, and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention and its advantages, reference is now made to the following description taken in conjunction with the accompanying drawings, wherein like numerals represent like parts, and which:

FIGURES 1A and 1B are diagrams illustrating an underground treatment system in accordance with one embodiment of the present invention;

FIGURE 2A is a diagram illustrating an underground treatment system in accordance with another embodiment of the present invention;

FIGURE 2B is a diagram illustrating an underground treatment system in accordance with another embodiment of the present invention;

FIGURE 3 is a diagram illustrating an inflatable packer in accordance with one embodiment of the present invention;

FIGURE 4 is a diagram illustrating formation of an underground treatment system in accordance with another embodiment of the present invention;

FIGURE 5 is a diagram illustrating an underground treatment system in accordance with one embodiment of the present invention;

FIGURE 6 is a diagram illustrating a top plan view of system 100 illustrated in FIGURE 4 in accordance with one embodiment of the present invention;

FIGURE 7 is a diagram illustrating a well bore pattern in accordance with another embodiment of the present invention;

FIGURE 8 is a diagram illustrating a well bore pattern in accordance with another embodiment of the present invention;

FIGURE 9A is a diagram illustrating an aligned or nested arrangement of well bore patterns within a subterranean zone in accordance with an embodiment of the present invention;

FIGURE 9B is a diagram illustrating an aligned or nested arrangement of well bore patterns within a subterranean zone in accordance with another embodiment of the present invention;

FIGURE 10 is a diagram illustrating a system for underground treatment of materials in accordance with another embodiment of the present invention;

FIGURE 11 is a diagram illustrating a system for underground treatment of subsurface materials in accordance with another embodiment of the present invention;

FIGURE 12 is a diagram illustrating a trumpet valve within a system for underground treatment of subsurface materials in accordance with an embodiment of the present invention;

FIGURE 13 is a diagram illustrating a system for underground treatment of subsurface materials in accordance with another embodiment of the present invention; and

FIGURE 14 is a flowchart illustrating a method for underground treatment of subsurface materials in accordance with another embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

FIGURE 1A and 1B are diagrams illustrating a method of providing an underground treatment system in accordance with one embodiment of the present invention.

Referring to FIGURE 1A, system 10 includes a well bore 12 extending from the surface 14 to below or

otherwise proximate to the level of a subterranean treatment zone 15. In FIGURES 1A and 1B, well bore 12 is illustrated substantially vertical; however, it should be understood that well bore 12 may be formed at other suitable angles. Substantially vertical means vertical or within 40° of vertical.

Subterranean treatment zone 15 may comprise a zone of precious metals mineable with an underground leachate treatment process, a zone of tar sand from which oil may be recoverable by an underground steam treatment process, a plume of underground contaminants treatable with an underground chemical or biological remediation process, or another suitable zone of materials treatable underground using the system and/or method of the present invention.

Enlarged cavities 20 and 22 are formed in the well bore 12. As described in more detail below, the enlarged cavities 20 and 22 provide a junction for intersection of the well bore 12 by an articulated well bore used to form subterranean well bore patterns. The enlarged cavities 20 and 22 may also provide a collection point from fluids drained from the zone 15. Enlarged cavity 20 may be formed at or above a vertical level corresponding to the top of the subterranean treatment zone 15, and cavity 22 may be formed at or below a vertical level corresponding to the bottom of the subterranean treatment zone 15. In this way, subterranean well bore patterns may be formed at or near the top and bottom of the subterranean treatment zone 15, as described further below. While the embodiment shown in FIGURES 1A and 1B shows two cavities, additional cavities may be formed so as to, for example, extend additional well bore patterns into the middle of the zone 15.

In one embodiment, the enlarged cavity 20 has a radius of approximately eight feet and a vertical dimension of approximately eight feet. In another embodiment, the cavity 20 may have a substantially rectangular cross section perpendicular to an articulated well bore for intersection by the articulated well bore and a narrow width through which the articulated well bore passes. The enlarged cavities 20 and 22 are formed using suitable under-reaming techniques and equipment. A portion of the well bore 12 may continue below the enlarged cavity 22 to form a sump 24 for the cavity 22. The well bore 12 may be lined with a suitable well casing 16 that with the illustrated embodiment, terminates at or above the level of the first cavity. In other embodiments, the cavity may be omitted if unnecessary for intersecting bores and/or not needed as a collection point.

An articulated well bore 30 extends from the surface 14 to the enlarged cavity 20 of the well bore 12. In the illustrated embodiment, the articulated well bore 30 includes a vertical portion 32, a first horizontal portion 34, and a first curved or radius portion 36 interconnecting the portions 32 and 34. In FIGURES 1A and 1B the portion 32 is illustrated substantially vertical; however, it should be understood that portion 32 may be formed at any suitable angle relative to surface 14. In the embodiment illustrated in FIGURES 1A and 1B, the portion 34 may lie substantially in a horizontal plane and intersect the enlarged cavity 20 of the well bore 12. Portion 34 may be formed at an angle relative to the surface 14 to allow the flow of fluid towards or away from the well bore 12.

In the embodiment illustrated in FIGURES 1A and 1B, the articulated well bore 30 is offset a sufficient

distance from the well bore 12 at the surface 14 to permit the large radius curved section 36 and any desired portion 34 to be drilled before intersecting the enlarged cavity 20. To provide the curved portion 36 with a radius of 100-150 feet, the articulated well bore 30 is offset a distance of about 300 feet from the well bore 12. This spacing minimizes the build angle of the curved portion 36 to reduce friction in the articulated well bore 30 during drilling operations. As a result, reach of the articulated drill string drilled through the articulated well bore 30 is maximized. In another embodiment, the articulated well bore 30 and the substantially vertical well bore 12 may be positioned next to each other at the surface 14 with the substantially vertical well bore 12 slanting underground, in this way providing the necessary radius of the curved portion 36 while minimizing the area of the surface footprint.

The articulated well bore 30 is drilled using an articulated drill string 40 that includes a suitable drown hole motor and bit 42. A measurement while drilling (MWD) device 44 is included in the articulated drill string 40 for controlling the orientation and direction of the well bore drilled by the motor and bit 42. The portion 32 of the articulated well bore 30 is lined with a suitable casing 38.

After the enlarged cavity 20 has been successfully intersected by the articulated bore 30, drilling is continued through the cavity 20 using the articulated drill string 40 in to appropriate drilling apparatus to provide a first subterranean well bore pattern 50 above the level of the zone 15. In FIGURE 1A, the well bore pattern 50 is illustrated substantially horizontal; however, well bore pattern 50 may be formed at any

suitable angle to allow for the flow of fluid towards and/or away from the zone 15. During this operation, gamma ray logging tools and conventional measurement while drilling devices may be employed to control and direct the orientation of the drill bit 42.

Well bore pattern 50 is shown edge-on in the cross-sectional view shown in FIGURE 1A; therefore, the details of the patterning are not shown. However, it will be understood that well bore pattern 50 may comprise a pattern shown in FIGURES 7-9 or another suitable pattern or patterns.

During the process of drilling the well bore pattern 50, drilling fluid or mud is pumped down the articulated drill string 40 and circulated out of the drill string 40 in the vicinity of the bit 42 where it is used to scour the bore hole and to remove formation cuttings. The cuttings are then entrained in the drilling fluid which circulates up through the annulus between the drill string 40 and the walls of the well bore 30 until it reaches the surface 14 where the cuttings are removed from the drilling fluid and the fluid is then recirculated. This conventional drilling operation produces a standard column of drilling fluid having a vertical height equal to the depth of the well bore 30 and produces a hydrostatic pressure on the well bore 30 corresponding to the well bore 30 depth.

To prevent drilling fluid from draining down into the portion of the well bore 12 below the cavity 20, during formation of the well bore pattern 50, air compressors 60 may be provided to circulate compressed air down a pipe 53 below the cavity 20, and back up through the articulated well bore 30. The circulated air velocity prevents drilling fluid and cuttings from draining into the bore below the cavity 20.

Referring to FIGURE 1B, after formatting of the first well bore pattern 50, the portion 32 of the articulated well bore 30 is extended downward and intersected with cavity 22 in a similar manner as described above. In the illustrated embodiment, as described above, a second well bore pattern 50 is drilled below the level of the zone 15. Prior to drilling of second pattern 52, the pipe 53 may be removed. A packer or plug 33 may be placed in the first curved or radiused portion 34 to prevent the short circuit flow of fluids into the cavity 20 and the first well bore pattern 50. Further details concerning the packer 33 are described in reference to FIGURE 3, below.

Well bore pattern 52 is shown edge-on in the cross-sectional view shown in FIGURE 1B; therefore, the details of the patterning are not shown. However, it will be understood that well bore pattern 52 may comprise a pattern shown in FIGURES 7-9 or another suitable pattern or patterns.

FIGURE 2A is a diagram illustrating an underground treatment system in accordance with another embodiment of the present invention.

Referring to FIGURE 2A, in well bore 12, the enlarged cavities 20 and 22, the articulated well bore 30, and the well patterns 50 and 52 are positioned and formed as previously described in connection with FIGURES 1A and 1B. In addition, a cavity 26 and well bore pattern 54 are illustrated, with the well bore pattern 54 penetrating the middle of the zone 15.

A down-hole pump 70 is placed in the cavity 22 proximate to the sump 24 so as to facilitate the pumping of fluid up from the sump 24. The pump is connected to the surface 14 via a tubing string 72 and maybe powered by sucker rods extending down through the tubing string

72. The sucker rods may be reciprocated by a suitable surface-mounted apparatus, such as a powered walking beam 76 to operate the down-hole pump 70. Tanks 75 and 77 may provide storage for unused and used treatment solution, and tank 79 may be provide storage for used treatment solution.

Packers 62, 64, 66 and 68 may be placed so as to provide a barrier to the movement of fluids. Packer 62 may be placed below cavity 20 in the bore 12. Packer 64 may be placed in the first curved or radiused portion 34. Packer 66 may be placed in the vertical portion of the articulated well bore 30 below the junction 67. Packer 68 may be placed below cavity 26 in the bore 12. Packers 62 and 68 may be provisioned so as to attach to the external surface of the pipe 74 and inflated via an air hose or tube (not shown). Packers 64 and 66 may be of an inflatable or another suitable type. Further details of a packer in accordance with one embodiment of the present invention is described in conjunction with FIGURE 3.

With the well bores, patterns and packers positioned as illustrated, a treatment solution 74 may be injected from tank 77 into the well bore pattern 50 via the well bore 12. A second treatment solution 76 may be injected from tank 75 into the well bore pattern 54 via the bore 30. The treatment solution 74 and 76 percolate through the zone 15 and are collected in the well bore pattern 52. In the illustrated embodiment, well bore pattern 52 may be angled slightly upward so as to facilitate the movement of the mixture of solution 74 and 76 into the cavity 22 and sump 24. The angle X° may be approximately 5° or another suitable angle. As the mixture collects in the cavity 22 and sump 24, the pump 70 lifts the mixture up to the surface 14 via the pipe 72 to be stored in tank 79.

Well bore patterns 50, 52, and 54 are shown edge-on in the cross-sectional view shown in FIGURE 2A; therefore, the details of the patterning are not shown. However, it will be understood that well bore patterns 50, 52, and 54 may comprise a pattern shown in FIGURES 7-9 or another suitable pattern or patterns.

The treatment solutions 74 and 76 may comprise a reagent, neutralizer, and leaching solution, or other suitable solution used to treat the zone 15. Treatment solutions 74 and 76 may comprise either a liquid or a gas. Treatment in this context may comprise neutralizing leaching, recovery, dissolving, oxidation, reduction, or other suitable process. Treatment may also comprise biological processes or biological mediated processes (including bioremediation) in which case the treatment solution may comprise bacteria, nutrients, or other materials which may affect the metabolism, respiration, or other processes of bacteria or other organisms. In a particular embodiment, the treatment may comprise stripping recoverable product from the zone 15. In yet another embodiment, the treatment solutions may comprise gases, such as CO_2, N_2, air, or steam, used to re-pressurize depleted formations.

FIGURE 2B is a diagram illustrating an underground treatment system in accordance with another embodiment of the present invention.

Referring to FIGURE 2B, the well bore 12, the enlarged cavities 20, 22, and 26, the sump 24, the articulated well bore 30, the articulated well bores 50, 52, and 54, downhole pump 70, tubing string 72, and tanks 77 and 79 are formed as previously described in connection with FIGURE 2A.

Injection pipe 82 is placed into the main bore of articulated well bore pattern 54. Packer 84 seals the

bore 54, leaving the distal end of the injection pipe 82 in the well bore pattern 54. Injection pipe 82 may inject a treatment solution 86 into well bore pattern 54. Driven by pressure, diffusion, or otherwise, the treatment solution 86 may travel upward and downward to articulate well bore patterns 50 and 52, respectively. The treatment solution is then collected and pumped to the surface via subsurface pump 70 in pipe 72 as described previously in connection with FIGURE 2A.

FIGURE 3 is a diagram illustrating an inflatable packer in accordance with one embodiment of the present invention. The packer illustrated in FIGURE 3 may be used in the embodiments shown in FIGURES 1B, 2A, 2B, 5, 10, 11, or 13, or in other embodiments of the present invention.

Referring to FIGURE 3, the packer 62 may be attached to the external surface of the pipe 72 which is placed within the well bore 12. The packer 62 may be placed below the cavity 20 or at another suitable location. An inflation hose or tube 80 allows for the inflation of the packer 62. In this way, the packer is operable to selectively prevent flow of the treatment fluid through a point within the common bore.

Although FIGURE 3 illustrates the packer as particularly shown in FIGURE 2B, the packer illustrated in FIGURE 3 may be used in the embodiments shown in FIGURES 1B, 2A, 2B, 5, 10, 11, or 13, or in other embodiments of the present invention.

FIGURE 4 is a diagram illustrating a dual radius articulated well system 100 in accordance with another embodiment of the present invention. In this embodiment, two discreet well bore patterns are formed in communication with a single well bore. For ease of illustration, formation of two well bore patterns is

described in conjunction with FIGURE 4; however, it should be understood that the formation of the well bore pattern may be duplicated for forming the additional well bore patterns.

Returning to FIGURE 4, a well bore 102 extends from the surface 14 to a first articulated well bore 104. The well bore 102 may be lined with a suitable well casing 106. A second well bore 108 extends from the intersection of the well bore 102 and the first articulated well bore 104 to a second articulated well bore 110. The second well bore 108 is in substantial alignment with the first well bore 102, such that together they form a continuous well bore. An extension 112 to the second well bore 104 extends from the intersection of the second well bore 104 and a second articulated well bore 110 to a depth below the coal seam 15. In FIGURE 4, well bores 102 and 108 are illustrated substantially vertical; however, it should be understood that well bores 102 and 108 may be formed having other angular orientations to accommodate surface 14 and/or subsurface treatment zone 15 geometric characteristics.

The first articulated well bore 104 includes a radius portion 114. The second articulated well bore 110 includes a radius portion 116. The radius portion 116 is generally sized smaller than radius portion 114 to accommodate intersection of the second articulated well bore 110 with the first articulated well bore 104. The first articulated well bore 104 communicates with an enlarged cavity 118. The enlarged cavity 118 is formed at the distal end of the first articulated well bore 104 at the level of zone 15. As described in more detail below, the enlarged cavity 118 provides a junction for intersection of a subsurface channel or well bore 120.

In one embodiment, the enlarged cavity 118 is formed having a radius of approximately eight feet and a vertical dimension which equals or exceeds the vertical dimension of the zone 15. The enlarged cavity 118 is formed using suitable under-reaming techniques and equipment. However, the enlarged cavity 118 may be formed having other suitable geometric characteristics to accommodate fluid accumulation within the enlarged cavity 118.

The well bore 120 is formed at the intersection of the second well bore 108 and the second articulated well bore 110. In FIGURE 4, well bore 120 is illustrated substantially horizontal and below the zone 15; however, it should be understood that well bore 120 may be formed at other angular orientations to accommodate the geometric characteristics of the zone 15. After the enlarged cavity 118 has been formed, drilling is continued through the cavity 118 to form a first well bore pattern 122. A second well bore/well bore pattern 124 may be drilled in a manner similar to that described above with respect to well bore pattern 120. In the illustrated embodiment, the second well bore/pattern 124 is drilled horizontally above the zone 15; however, it should be understood that they may be formed at other orientations.

The well bore patterns 122 and 124 may include sloped, undulating, or other inclinations. During drilling of the well bore patterns 122 and 124 gamma ray logging tools and conventional measurement while drilling devices may be employed to control and direct the orientation of drilling to retain the first well bore pattern 122 to provide substantially uniform coverage of a desired area. The well bore patterns 122 and 124 may

comprise patterns as illustrated in FIGURES 7-9; however, other suitable well bore patterns may also be used.

FIGURE 5 is a diagram illustrating an underground treatment system comprising the well bore system formed as described in conjunction with FIGURE 4.

Referring to FIGURE 5, after the well bores and desired well bore patterns have been drilled in accordance with FIGURE 4, the articulated drill string 40 is removed from the well bores. A down hole pump 70 is disposed in the lower portion of the well bore 108 above the extension 112. Treatment fluids are injected or allowed to flow into well bore pattern 124. From well bore pattern 124, the treatment fluids may travel down through zone 15 to well bore pattern 122 to be recovered using down hole pump 70.

The extension 112 provides a reservoir for accumulated fluids allowing intermittent pumping without adverse effects of a hydrostatic head caused by accumulated fluids in the well bore.

The down hole pump 70 is connected to the surface 14 via a tubing string 72 and may be powered by sucker rods extending down through the tubing string 72. The sucker rods (not shown) are reciprocated by a suitable surface mounted apparatus, such as a powered walking beam 76 to operate the down hole pump 70. The down hole pump 70 is used to remove treatment solution 74 via the well bore pattern 122 after treatment of the 15. Once the treatment solution is removed to the surface, the treatment solution may be processed so as to remove precious metals, contaminants, or other components removed from the zone 15 during subsurface treatment.

FIGURE 6 is a diagram illustrating a top plan view of system 100 illustrated in FIGURE 4 in accordance with one embodiment of the present invention.

Referring to FIGURE 6, each of three articulated well bores 120 and articulated well bores 114 extend from well bore 108 in a position approximately 120 degrees apart from each other. Well bore 108 is drilled in a surface location at the approximate center of a desired total well bore area. As described above, articulated well bores 120 are drilled from a surface location proximate to or in common with the well bore 108. Well bore patterns 122 and 126 are drilled proximate to the target subterranean resource from the articulated well bores 120 and 114. Also from each of the articulated well bores 120, an enlarged cavity 118 is formed to collect fluid draining from the well bore patterns 122. Well bores 124 and well bore pattern 126 are also drilled in a position approximated 120 degrees from each other. However well bore 124 is positioned so as to bisect the 120 degree angle formed by well bores 114 and 120. In this way, the well bore patterns 126 are offset from well bore patterns 122, thereby increasing the travel distance of fluids migrating between well bore pattern 122 and well bore pattern 126. Each of three subsurface channel or well bores 114 is drilled to connect each of the enlarged cavities 118 with the well bore 108 as described above in connection with FIGURE 4.

Treatment solution may be injected into well bore patterns 126 and may drain into well bore patterns 122, where it is collected in the enlarged cavities 118. From the enlarged cavities 118, the fluids pass through the well bores 114 and into the well bore 108. Once the fluids have been collected in the well bore 108, they may be removed to the surface by the methods as described above.

FIGURES 7-8 are diagrams illustrating well bore patterns for enhanced access to subterranean resources in

accordance with embodiments of the present invention. FIGURES 7-8 illustrate a plan view of the well bore patterns. It will be understood that FIGURES 7-8 may illustrate horizontal patterns viewed at an overhead view, or illustrate non-horizontal patterns.

In the embodiments shown in FIGURES 7-8, the well bore patterns comprise pinnate patterns that have a main or central well bore with generally symmetrically arranged and appropriately spaced lateral well bores extending from each side of the main well bore. The pinnate pattern approximates the pattern of veins in a leaf or the design of a feather in that it has similar, substantially parallel, auxiliary well bore bores arranged in substantially equal and parallel spacing on opposite sides of an axis. The pinnate well bore pattern with its main or central bore and generally symmetrically arranged and appropriately spaced auxiliary lateral well bore bores on each side provides a uniform pattern for injecting and/or draining fluids into or from a subterranean zone. As described in more detail below, the pinnate pattern provides substantially uniform coverage of areas of various shapes. It will be understood that other suitable well bore patterns may be used in accordance with the present invention. In accordance with various embodiments of the present invention, lateral bores may be substantially horizontal or may be non-horizontal.

FIGURE 7 is a diagram illustrating a well bore pattern 150 in accordance with an embodiment of the present invention. In this embodiment, the well bore pattern 150 provides coverage of a substantially diamond or parallelogram-shaped area 152 of a subterranean zone. A number of the well bore patterns 150 may be used together to provide uniform coverage of a large

subterranean region. The articulated well bore 30 defines a first corner of the area 152. The well bore pattern 150 includes a main well bore 154 extending diagonally across the area 152 to a distant corner 156 of the area 152.

A plurality of lateral well bores 160 extend from the opposites sides of well bore 154 to a periphery 162 of the area 152. The lateral well bores 160 may mirror each other on opposite sides of the well bore 154 or may be offset from each other along the well bore 154. Each of the lateral well bores 160 includes a radius curving portion 164 extending from the well bore 154 and an elongated portion 166 formed after the curved portion 164 has reached a desired orientation. For uniform coverage of the area 152, pairs of lateral well bores 160 are substantially equally spaced on each side of the well bore 154 and extend from the well bore 154 at an angle of approximately sixty degrees. The lateral well bores 160 shorten in length based on progression away from the bore 30 in order to facilitate drilling of the lateral well bores 160. The quantity and spacing of lateral well bores 160 may be varied to accommodate a variety of resource areas, sizes and well bore requirements. For example, lateral well bores 160 may be drilled from a single side of the well bore 154 to form a one-half pinnate pattern.

The well bore 154 and the lateral well bores 160 are formed by using an articulated drill string and an appropriate drilling apparatus. During this operation, gamma ray logging tools and conventional measurement while drilling (MWD) technologies may be employed to control the direction and orientation of the drill bit.

FIGURE 8 illustrates a well bore pattern 188 in accordance with another embodiment of the present

invention. The well bore pattern 188 includes three discrete well bore patterns 180 each draining a portion of a region covered by the well bore pattern 188. Each of the well bore patterns 180 includes a main well bore 184 and a set of lateral well bores 186 extending from main well bore 184. In the tri-pinnate pattern embodiment illustrated in FIGURE 8, each of the well bores 184 and 186 are drilled from a common articulated well bore 144 and fluid and/or gas may be removed from or introduced into the subterranean zone through a well bore 146 in communication with each well bore 184. This allows tighter spacing of the surface production equipment, wider coverage of a well bore pattern and reduces drilling equipment and operations.

In the embodiment illustrated in FIGURE 8, the spacing between each well bore 184 is substantially equal at an angle of approximately 120 degrees from each other, thereby resulting in each well bore pattern 180 extending in a direction approximately 120 degrees from an adjacent well bore pattern 180. However, other suitable well bore spacing angles, patterns or orientations may be used.

In the embodiment illustrated in FIGURE 8, each well bore pattern 180 also includes a set of lateral (or sub-lateral) well bores 198 extending from lateral well bores 186. The lateral well bores 198 may mirror each other on opposite sides of the lateral well bore 186 or may be offset from each other along the lateral well bore 186. Each of the lateral well bores 198 includes a radius curving portion 194 extending from the lateral well bore 186 and an elongated portion 196 formed after the curved portion 194 has reached a desired orientation. For uniform coverage of the region 190, pairs of lateral well bores 198 may be disposed substantially equally spaced on each side of the lateral well bore 186. Additionally,

lateral well bores 198 extending from one lateral well bore 186 may be disposed to extend between or proximate lateral well bores 198 extending from an adjacent lateral well bore 186 to provide uniform coverage of the region 190. However, the quantity, spacing, and angular orientation of lateral well bores 198 may be varied to accommodate a variety of areas, sizes and well bore requirements.

Area 197 shows an example of lateral bores connecting at their distal ends. Area 199 shows an example of lateral bores not connecting at their distal ends. It will be understood that the patterns used in the present invention may comprise patters of connecting lateral bores, patterns of non-connecting lateral bores, or patterns comprising mixtures of connecting and non-connecting bores.

FIGURE 9A is a diagram illustrating an aligned or nested arrangement of well bore patterns within a subterranean zone in accordance with an embodiment of the present invention. In this embodiment, three discreet well bore patterns 180 are used to form a series of generally hexagonally configured well bore patterns 200. A desired geometrical configuration or access shape can be obtained. The quantity of discreet well bore patterns 180 may also be varied to produce other geometrically-configured well bore patterns such that the resulting well bore patterns may be nested to provide uniform coverage of a subterranean zone.

FIGURE 9B is a diagram illustrating an aligned or nested arrangement of well bore patterns within a subterranean zone in accordance with another embodiment of the present invention.

Referring to FIGURE 9B, hexagonal well bore patterns 200 are formed as described above. For clarity, the

lateral bores are not shown in FIGURE 9B; however, it will be understood that the patterns 200 comprise lateral bore patterns as shown in FIGURE 9A or other suitable patterns.

In the embodiment shown in FIGURE 9B, some of the well bore patterns 200 are used as injection patterns 202 for injecting treatment solution. The remaining well bore patterns 200 are used as recovery patterns 204 for recovering the injected treatment solution after treatment of an underground treatment zone. Injection patterns 202 and recovery patterns 204 may be placed at the same horizontal level or, in an alternative embodiment, may be staggered.

FIGURE 10 is a diagram illustrating a method and system for underground treatment of materials in accordance with another embodiment of the present invention.

Referring to FIGURE 10, substantially vertical well bore 254 is drilled through subsurface treatment zone 15. Well bore patterns 250 and 252 are drilled from bore 254 at junctions 256 and 258, respectively. The well bore patterns 250 and 252 lay in a substantially vertical plane on the sides of a subsurface zone 15. Well bore patterns 250 and 252 are shown edge-on in the cross-sectional view shown in FIGURE 10; therefore, the details of the patterning are not shown. It will be understood that well bore patterns 250 and 252 may comprise one of the patterns described in reference to FIGURES 7-9 or another suitable pattern or patterns.

A subsurface pump 262 is connected to pipe 264 which leads to the surface 14. One or more packers or plugs may be placed in the vertical bore 254 below the junctions 256 and 258. In the illustrated embodiment, three packers - 265, 267, and 269 - are placed in the

vertical bore 254. Each may be individually inflated or deflated.

Treatment solution 74 is injected into well bore patterns 268 and 270, where it may travel from the well bore patterns through zone 15. Also, depending on whether any of packers 265, 267, or 269 are inflated, treatment solution 74 may also enter zone 15 from vertical bore 254. The treatment solution 74 is recovered after travelling through zone 15 in cavity 260 of bore 254. It will be understood that, in accordance with another embodiment, bore 254 may be used for injection of the treatment solution and bores 250 and 252 as the recovery bore.

FIGURE 11 is a diagram illustrating a system for underground treatment of subsurface materials in accordance with another embodiment of the present invention.

Referring to FIGURE 11, injection patterns 312 and recovery patterns 314 are drilled from four substantially vertical well bores 300, 302, 304, 306, and 308 in a manner similar to that described above. The vertical bores, injection patterns, and recovery patterns may comprise a common bore; however, inflatable packers 62 may be placed at various locations to selectively prevent flow of a treatment solution or other fluid within the common bore. In the illustrated embodiment, packers 62 are placed in vertical well bores 300 and 308 below the junctions 328 and 330, respectively. Packers 62 are also placed in vertical well bores 302, 304, and 306 below the cavities 20. In this way, treatment solution may be injected through the vertical well bores and into the injection patterns so as to percolate through the subsurface treatment zone 15. The treatment solution is then recovered in the recovery patterns and pumped via

pumps 70 through pipes 72 to the surface 14. Surface pump units 310 may comprise a pump jack or other apparatus to facilitate the operation of the pumps 70.

Well bore patterns 312 and 314 are shown edge-on in the cross-sectional view shown in FIGURE 11; therefore, the details of the patterning are not shown. However, it will be understood that these well bore patterns may comprise a pattern shown in FIGURES 7-9 or another suitable pattern or patterns.

The packers 62 may be placed in other suitable locations and may be placed in different locations and/or at different times so as to facilitate a secondary treatment schedule, a second treatment solution, or focused treatment of a particular portion of zone 15. In this way, the common bore comprising the injection patterns and the recovery patterns, when used with the inflatable packers 62, becomes an underground "circuit" system enabling a dynamic and managed course of treatment of subsurface treatment zone 15.

FIGURE 12 is a diagram illustrating a trumpet valve with a system for underground treatment of subsurface materials in accordance with one embodiment of the present invention.

Referring to FIGURE 12, the vertical well bore 350 is intersected by horizontal well bore patterns 352, 354, and 356. The trumpet valve 358 may allow for the selective flow of treatment solution or other fluids from the selected well bore patterns down vertical bore 350.

The trumpet valve 358 may comprise a solid cylinder drilled with a T-shaped cavity 360. The position of the valve 358 is controlled by control wire 362, which may be controlled from the surface via an electrically-controlled winch, sucker rod, or with other suitable subsurface or surface means.

In the example shown in FIGURE 12, the trumpet valve 358 is placed in a position so as to allow for fluids to drain from bore pattern 354 and down vertical bore 350, and also as to prevent fluids from bores 352 and 356 from travelling below the valve and down vertical bore 350. Changing the position of valve 358 may allow for the selection of other flow arrangements.

FIGURE 13 is a diagram illustrating a system for underground treatment of subsurface materials in accordance with another embodiment of the present invention.

Referring to FIGURE 13, the system includes an entry well bore 400, a slant well 402, a pipe 404, a packer 406, a subsurface pump 408, well patterns 410 and 412, extended portion 414, and storage tanks 416 and 418. The well bores 402 and well bore patterns 410 and 412 are drilled from the surface 14; well bore pattern 410 is drilled above subsurface zone 15 and well bore pattern 412 is drilled below subsurface zone 15. Treatment solution may be injected into the bore 404 and diverted into well bore pattern 410 by packer 406. The treatment solution may travel through zone 15 and into well bore pattern 412 to be collected and pumped to the surface by subsurface pump 408 in extended portion 414. Unused and used treatment solution would be stored in tanks 416 and 418, respectively. In the illustrated embodiment, the extended portion 414 may allow for the collection of used treatment solution in a sufficient volume to make the use of enlarged cavities unnecessary.

In another embodiment, well patterns 410 and 412 may both comprise injection patterns for sequestration of gaseous emissions from internal combustion engines, or of other materials for which disposal by underground sequestration may be appropriate. For example, certain

underground formations such as coal have high absorption affinities for carbon dioxide, sulfur oxides, nitrogen oxides, and/or other gases or other materials that may comprise regulated substances or pollutants. In accordance with this embodiment, subsurface zone 15 may comprise a sequestration zone such as a coal seam into which the materials such as carbon dioxide may be sequestered. Well bore patterns 410 and 412 may be drilled proximate to the sequestration zone (adjacent to and/or within the zone) and the materials injected into the well bore patterns. In a particular embodiment, the materials comprise gases such as carbon dioxide that may first be entrained in water or another liquid. The liquid may act as a carrier medium, and the gas/carrier medium mixture is pumped into the well bore patterns with the aid of a surface pump. The pinnate pattern may provide for an increased surface area of the underground injection zone, thus providing for more efficient and effective sequestration.

FIGURE 14 is a flowchart illustrating a method for underground treatment of subsurface materials in accordance with another embodiment of the present invention.

Referring to FIGURE 14, the method begins with step 600 wherein a suitable drilling location is chosen. The location may be chosen based upon fairly complete knowledge concerning the shape, size, and orientation of the underground treatment zone 15, or may be chosen with the expectation that the drilling operations will yield data concerning the shape, size, and orientation of the underground treatment zone 15 and the drilling patterns and other drilling locations will be chosen accordingly upon receipt and analysis of that data.

Proceeding to step 601, a suitable network system is selected and formed. In the illustrated embodiment, the formation of the selected network system as is described below in relation to steps 602-612. It will be understood that network systems may be selected and formed with other methods in accordance with various embodiments of the present invention. In the illustrated embodiment, at step 602, a substantially vertical well is drilled. At step 604, cavities may be formed as described in reference to FIGURES 1A and 1B to facilitate intersection of an articulated well bore with the substantially vertical well bore.

Proceeding to step 606, an articulated well bore is drilled so as to intersect the cavities and form a main bore for the injection pattern. At 608, laterals from the articulated well bore are drilled to form an injection pattern. The injection pattern may comprise a well bore patterns as described in reference to FIGURES 7-9 or may comprise another suitable pattern or patterns. The injection pattern may be predetermined. Alternatively, the drilling of the injection pattern and the other bores may provide data concerning the shape, size, and orientation of the underground treatment zone 15. In this way, the zone 15 may be delineated during drilling operations and the injection pattern may be modified to provide suitable coverage of the zone 15.

Proceeding to step 610, the articulated well bore is drilled so as to intersect the cavities and form a main bore for the recovery pattern. At 612, laterals from the articulated well bore are drilled to form a recovery pattern. The recovery pattern may comprise a well bore patterns as described in reference to FIGURES 7-9 or may comprise another suitable pattern or patterns. The recovery pattern may be predetermined. Alternatively,

the drilling of the recovery pattern and the other bores may provide data concerning the shape, size, and orientation of the underground treatment zone 15. In this way, the zone 15 may be delineated during drilling operations and the recovery pattern may be modified to provide suitable coverage of the zone 15.

The injection pattern and the recovery pattern may substantially overlay one another. Alternatively, the recovery pattern may be horizontally offset from the injection pattern so as to maximize the distance traveled by the treatment solution through the zone 15 from the injection pattern to the recovery pattern.

At decisional step 614, it is determined wither the injection and recovery patterns provide sufficient coverage of the subsurface treatment zone 15. If the injection and recovery patterns do not provide sufficient coverage of the subsurface treatment zone 15, the no branch of decisional step 614 returns to step 602.

If the injection and recovery patterns provide sufficient coverage of the subsurface treatment zone 15, the yes branch of decisional step 614 leads to step 616, wherein suitable injection and recovery equipment is installed. Such equipment may comprise storage tanks, subsurface pumps, pipes, sucker rods, walking beams, and other suitable equipment.

At step 618, treatment solution is injected into the injection pattern. The treatment solution migrates through the subsurface treatment zone 15 and, at step 620, is recovered in the recovery pattern, along with dissolved precious metals, contaminants, or other products of the treatment of zone 15. Proceeding to step 622, these byproducts are recovered from the treatment solution. Such recovery may take place at the surface using suitable recovery equipment and processes.

Recovered treatment solution may be regenerated so as to be re-injected and used again for treatment.

At decisional step 624 it is determined wither the treatment of the subsurface treatment zone 15 is complete. If treatment of the subsurface treatment zone is complete, then the yes branch of decisional step 624 leads to step 626 wherein equipment is removed from the site and wells capped. If treatment of the subsurface treatment zone is not complete, then the no branch of decisional step 624 returns to step 618 for further injection, treatment, and recovery.

Although the present invention has been described with several embodiments, various changes and modifications may be suggested to one skilled in the art. It is intended that the present invention encompass such changes and modifications as fall within the scope of the appended claims.

WHAT IS CLAIMED IS:

1. A method for underground treatment of subsurface materials, comprising:

providing an injection pattern and a recovery pattern, the injection pattern and the recovery pattern located proximate to a subsurface treatment zone and at least one of the injection pattern and the recovery pattern comprising a plurality of lateral bores extending from a main bore;

injecting a treatment solution through the injection pattern; and

recovering the treatment solution through the recovery pattern.

2. The method of Claim 1, wherein the injection pattern and the recovery pattern both comprise a plurality of lateral bores extending from a main bore.

3. The method of Claim 1, wherein at least one of the injection patterns and the recovery pattern comprise a pinnate pattern.

4. The method of Claim 1, wherein the injection pattern and the recovery pattern both comprise a pinnate pattern.

5. The method of Claim 1, wherein a common bore comprises the injection pattern and the recovery pattern.

6. The method of Claim 5, further comprising:

providing at least one packer, the packer operable to selectively prevent flow of the treatment solution through a point within the common bore.

7. The method of Claim 1, wherein at least one of the injection pattern and the recovery pattern are substantially horizontal.

8. The method of Claim 1, wherein the subsurface treatment zone comprises a zone of contamination.

9. The method of Claim 1, wherein the subsurface treatment zone comprises an underground resource.

10. The method of Claim 9, wherein the underground resource comprises a precious metal deposit.

11. A system for underground treatment of subsurface materials, comprising:

an injection pattern and a recovery pattern, the injection pattern and the recovery pattern located proximate to a subsurface treatment zone and at least one of the injection pattern and the recovery pattern comprising a plurality of lateral bores extending from a main bore; and

a treatment solution, the treatment solution operable to be injected through a treatment solution through the injection pattern and recovered through the recovery pattern.

12. The system of Claim 11, wherein the injection pattern and the recovery pattern both comprise a plurality of lateral bores extending from a main bore.

13. The system of Claim 11, wherein at least one of the injection patterns and the recovery pattern comprise a pinnate pattern.

14. The system of Claim 11, wherein the injection pattern and the recovery pattern both comprise a pinnate pattern.

15. The system of Claim 11, wherein a common bore comprises the injection pattern and the recovery pattern.

16. The system of Claim 15, further comprising:

providing at least one packer, the packer operable to selectively prevent flow of the treatment solution through a point within the common bore.

17. The system of Claim 11, wherein at least one of the injection pattern and the recovery pattern are substantially horizontal.

18. The system of Claim 11, wherein the subsurface treatment zone comprises a zone of contamination.

19. The system of Claim 11, wherein the subsurface treatment zone comprises an underground resource.

20. The system of Claim 19, wherein the underground resource comprises a precious metal deposit.

21. A system for disposal of a material comprising:

an injection pattern located proximate to an underground sequestration zone and comprising a plurality of lateral bores extending in a pinnate pattern from a main bore; and

an injection mechanism operable to inject the material into the injection pattern.

22. The system of Claim 21 wherein the underground sequestration zone comprises a coal seam.

23. The system of Claim 21 wherein the material comprises carbon dioxide.

24. The system of Claim 21 wherein the injection mechanism comprises a surface pump.

25. The system of Claim 21 wherein the injection mechanism comprises means to entrain the material into a liquid carrier medium.

FIG. 1A

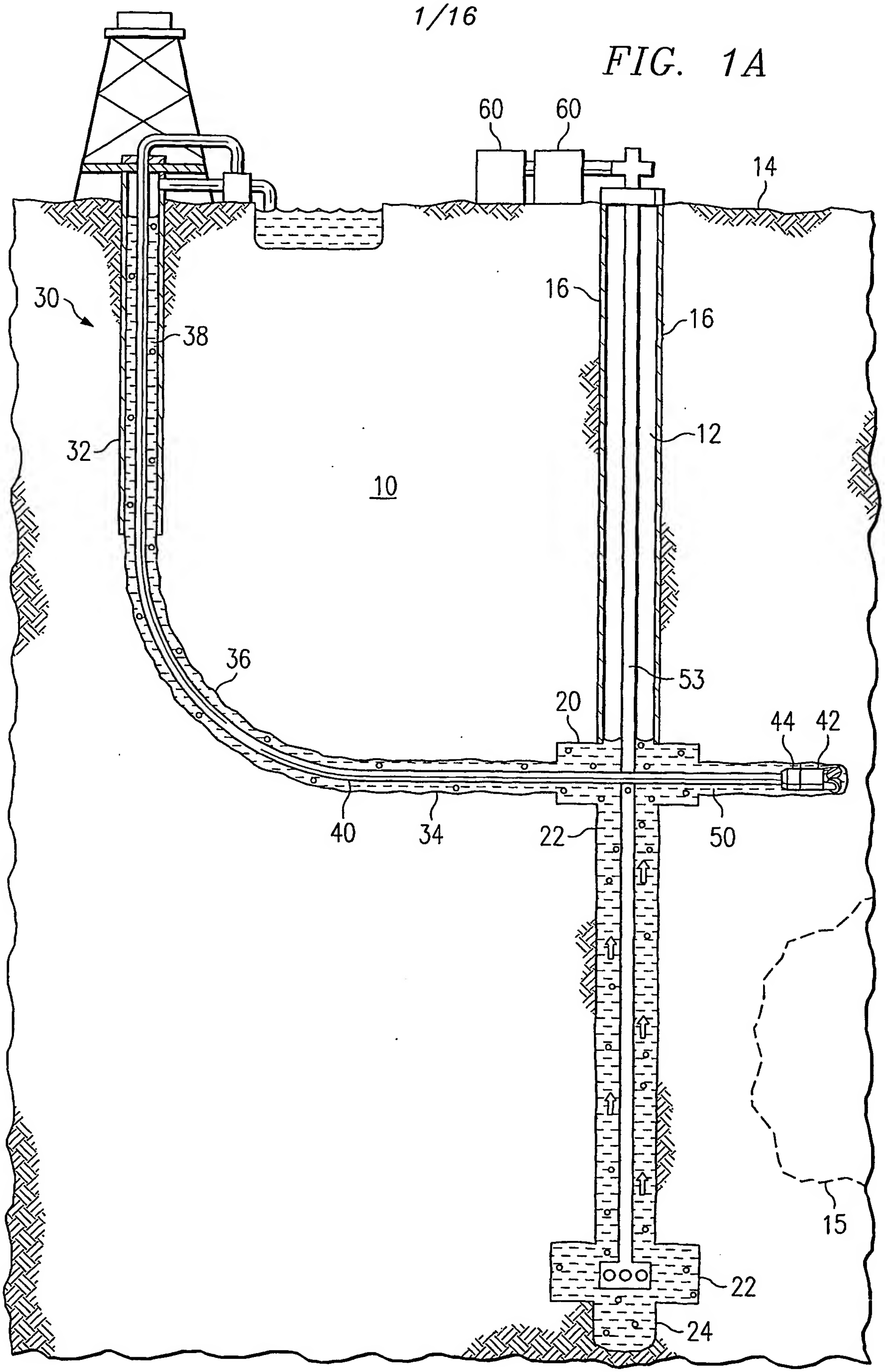
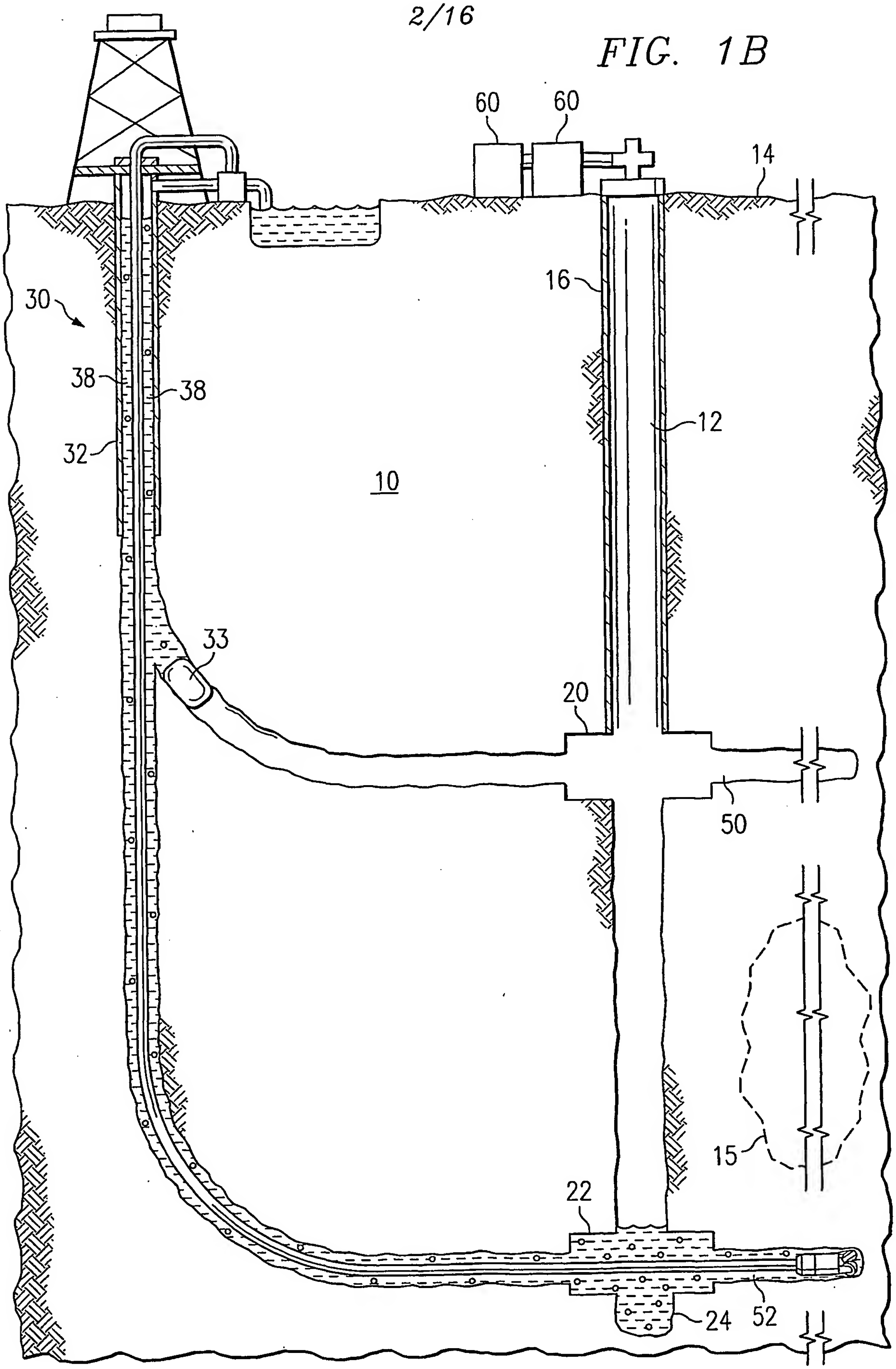


FIG. 1B



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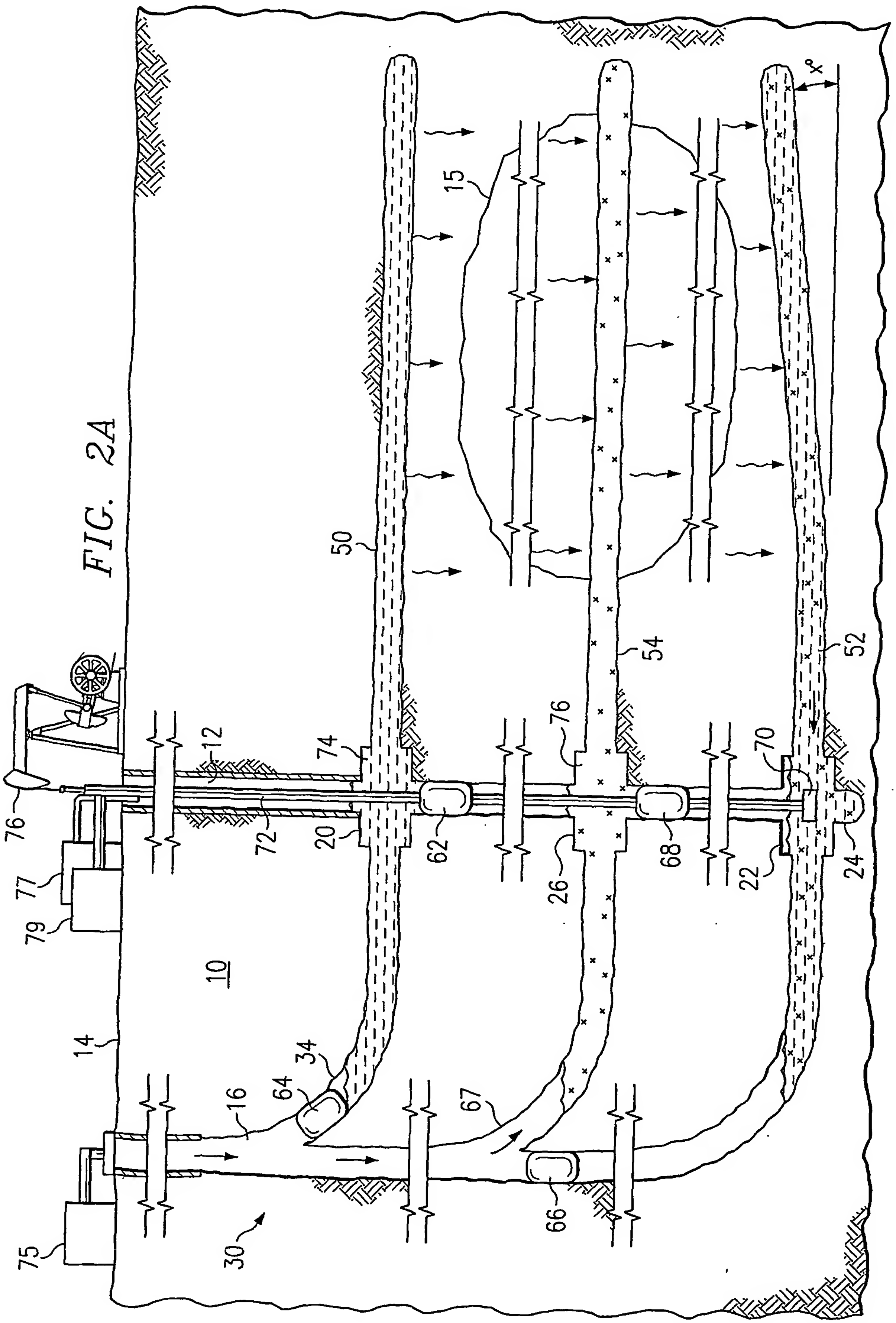
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FIG. 2A

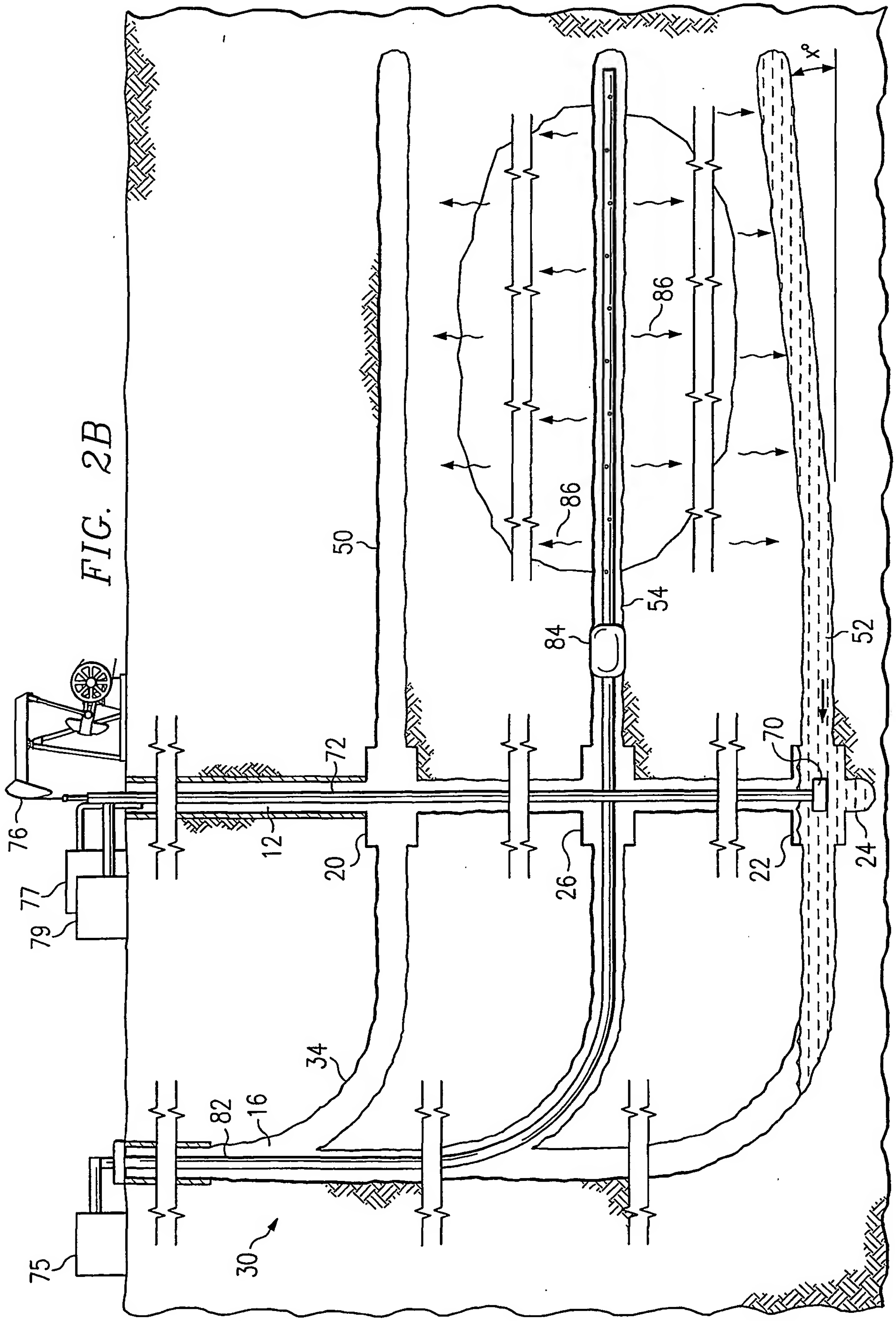


FIG. 2B

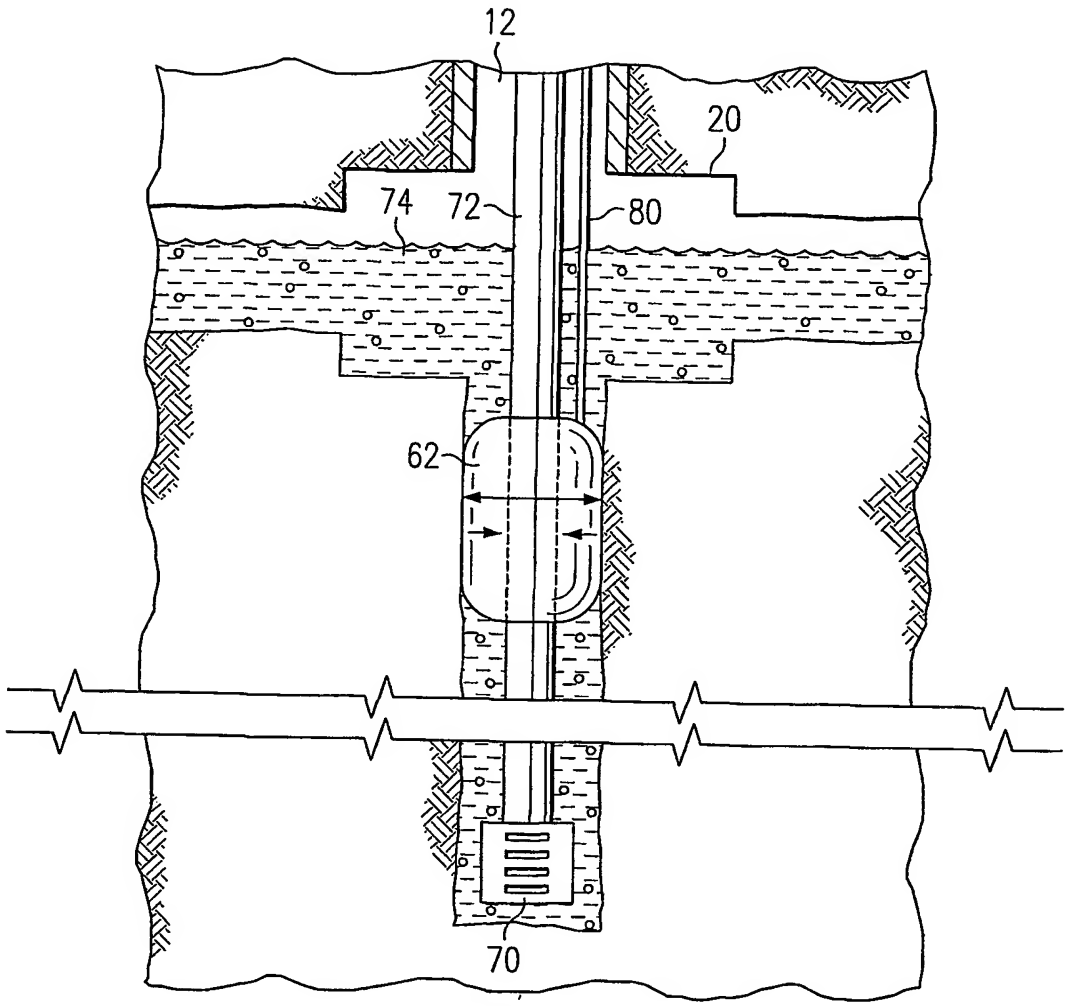


FIG. 3

FIG. 4

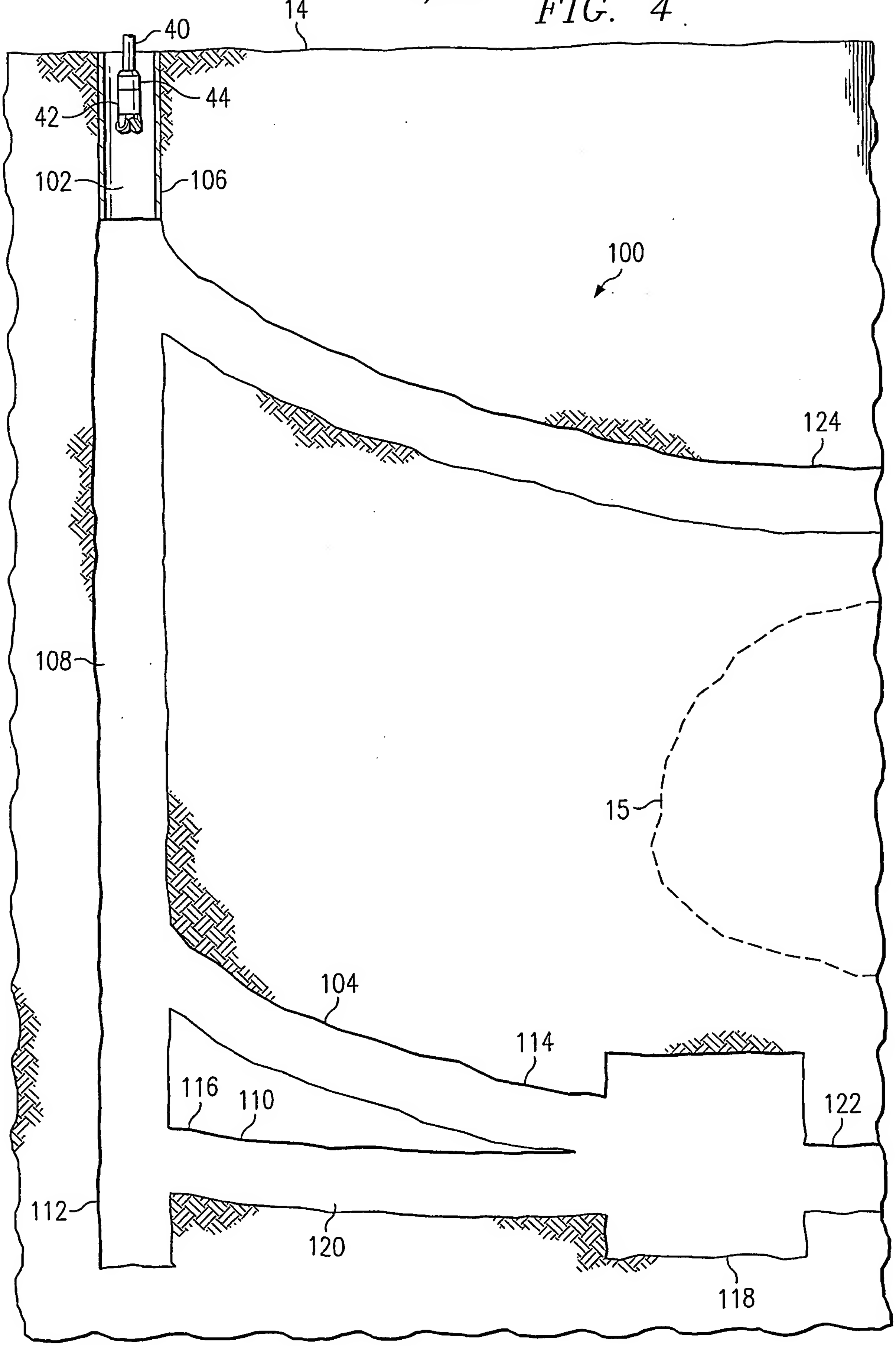
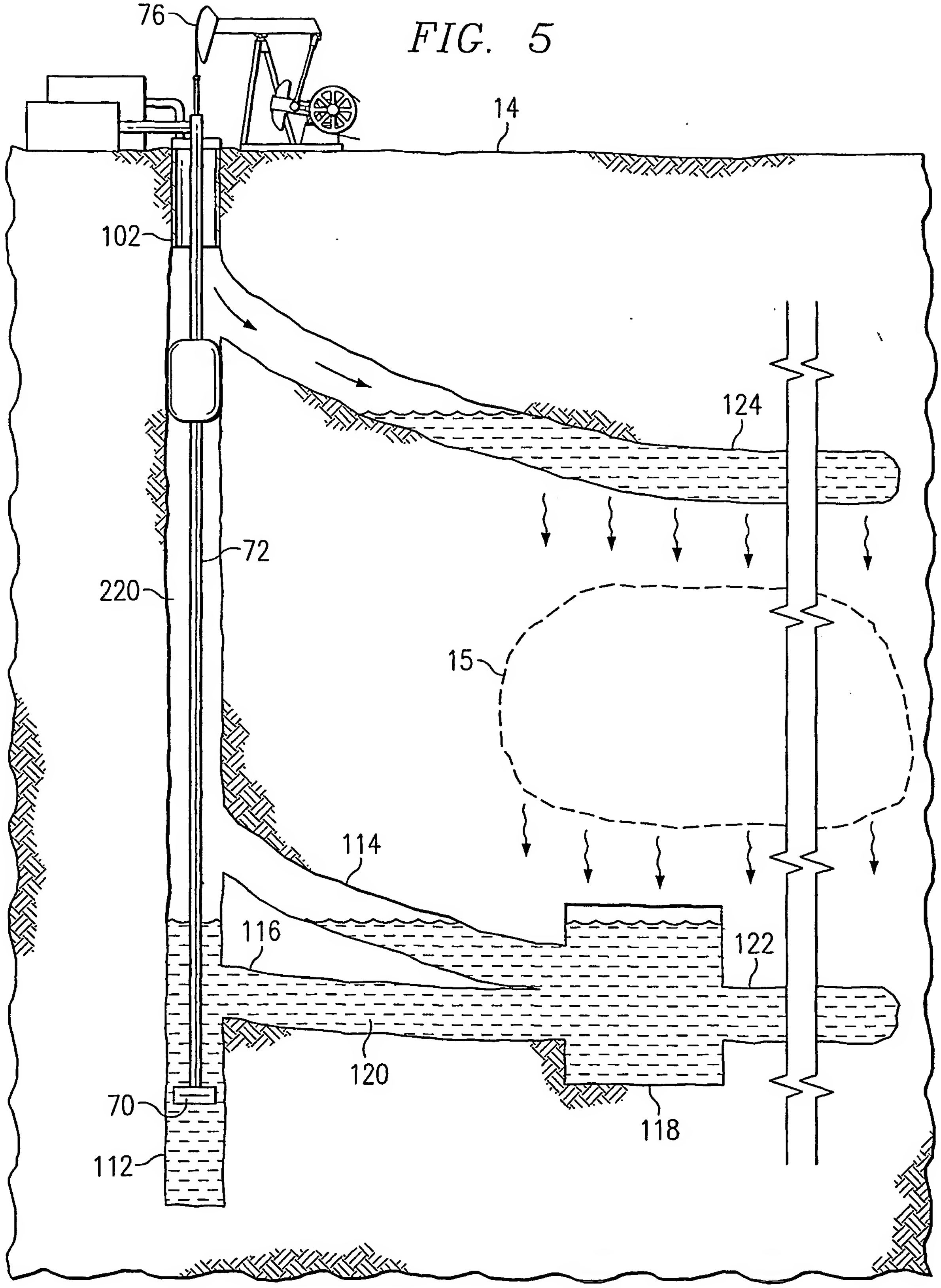


FIG. 5



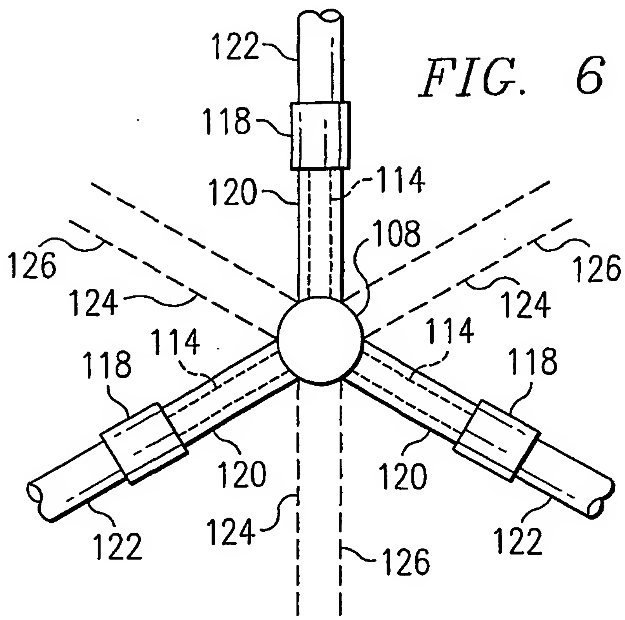

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FIG. 6

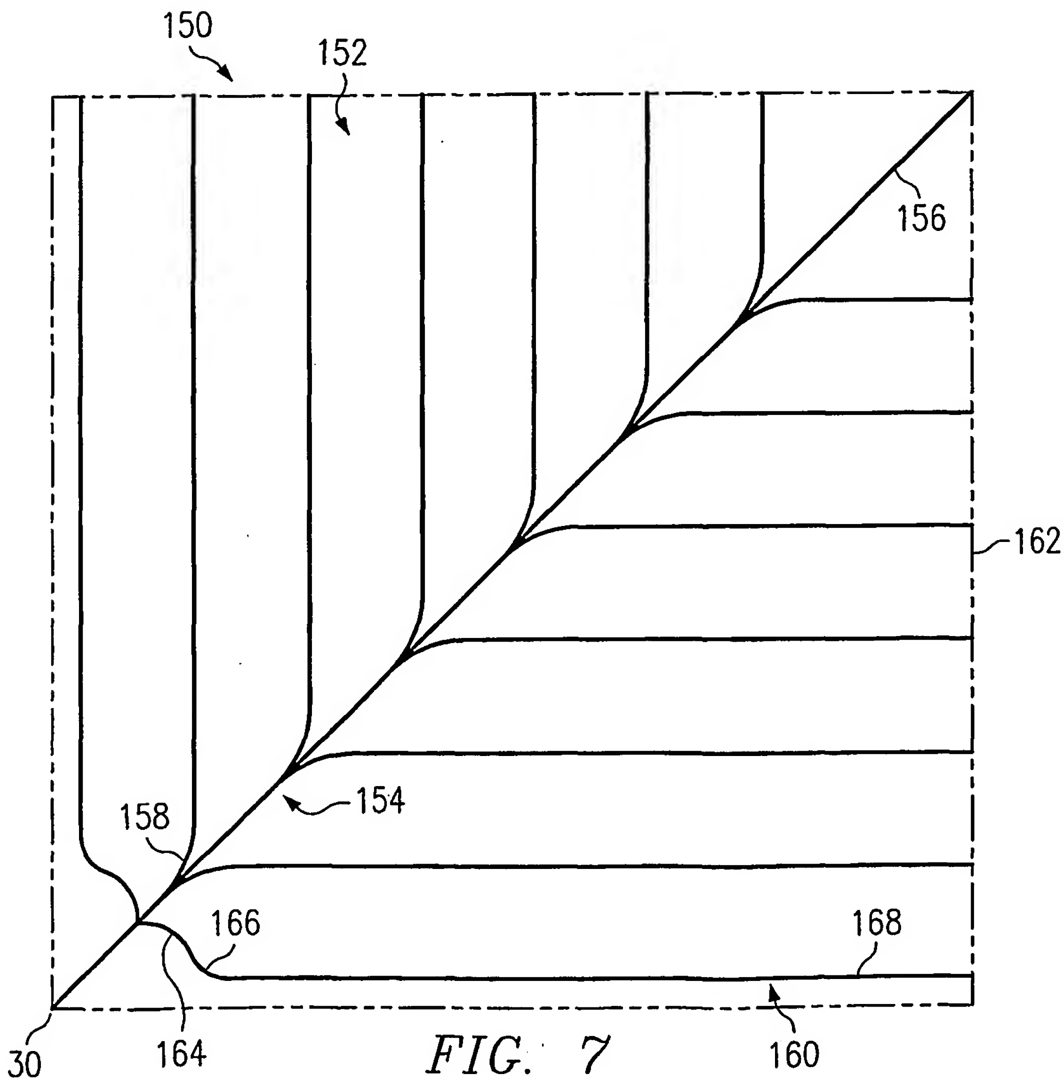
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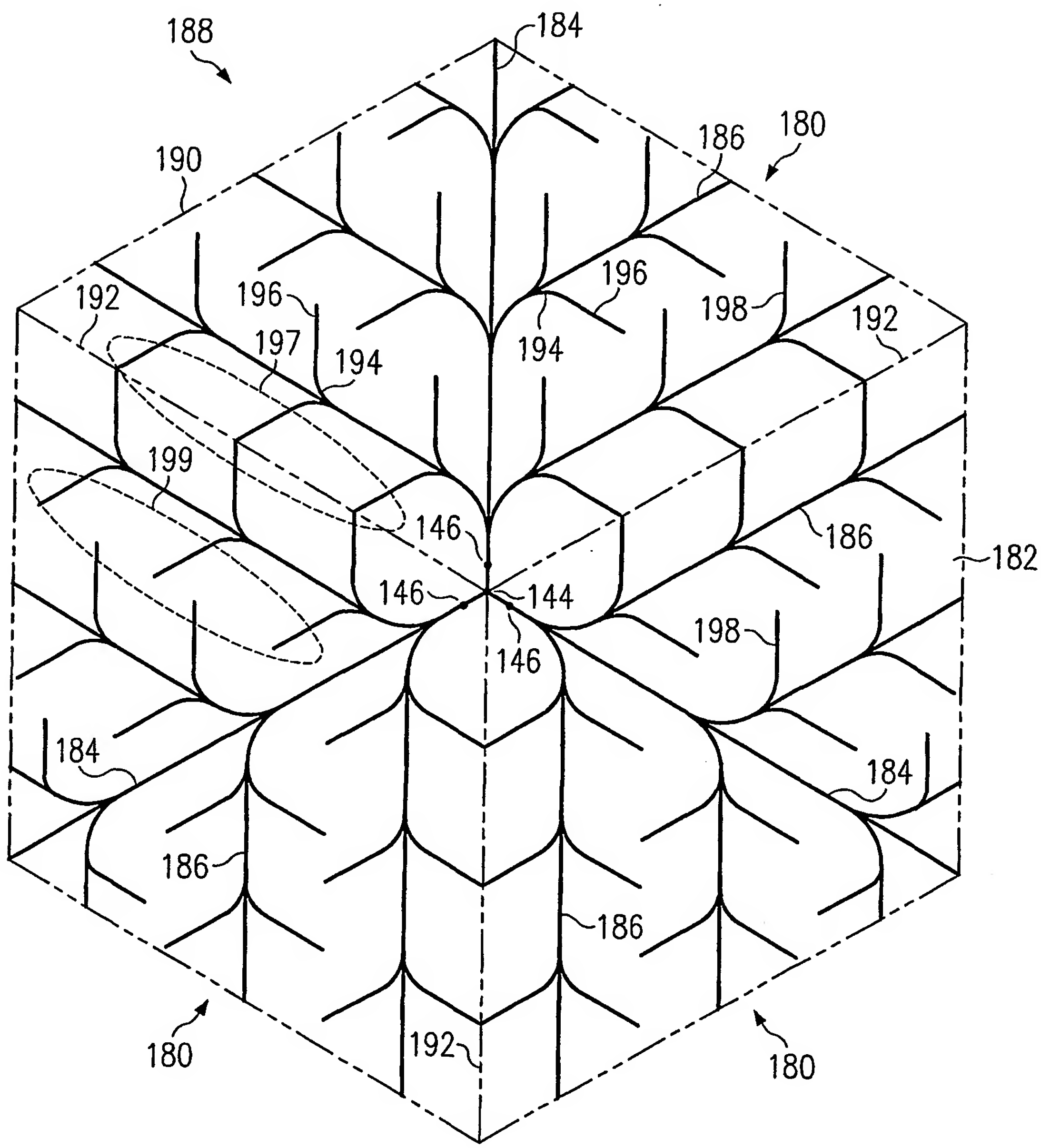
FIG. 7

FIG. 8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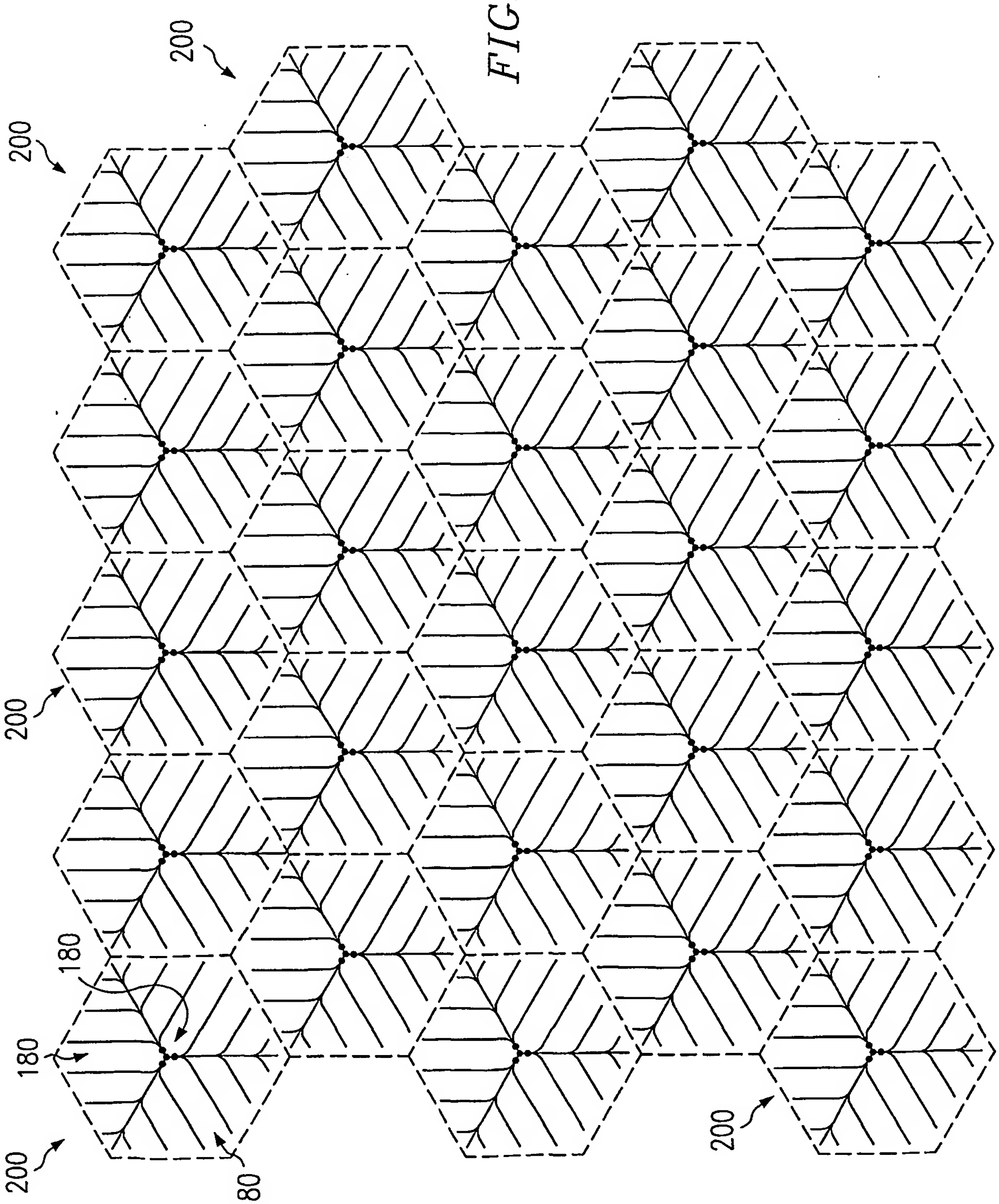


FIG. 9A

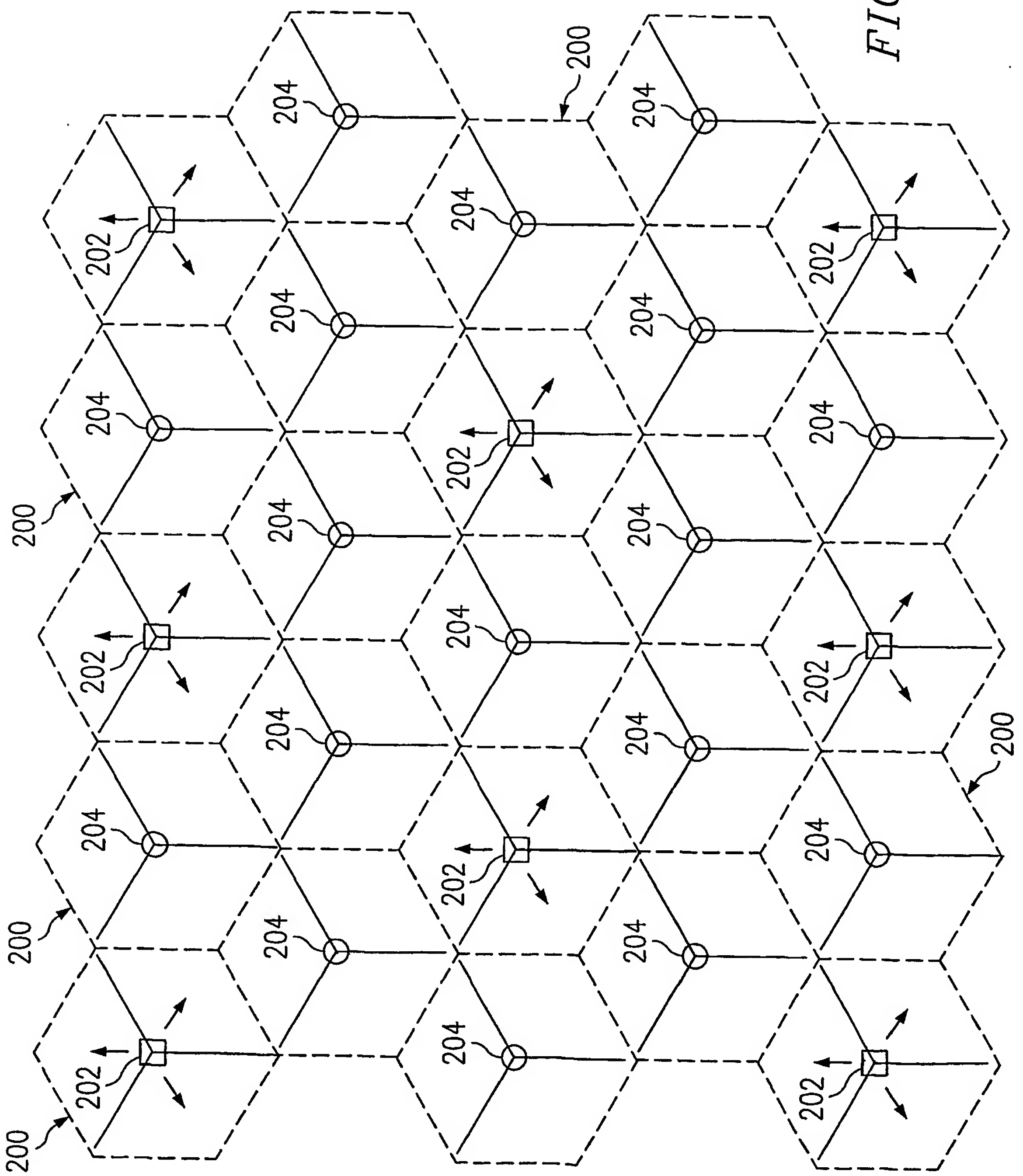
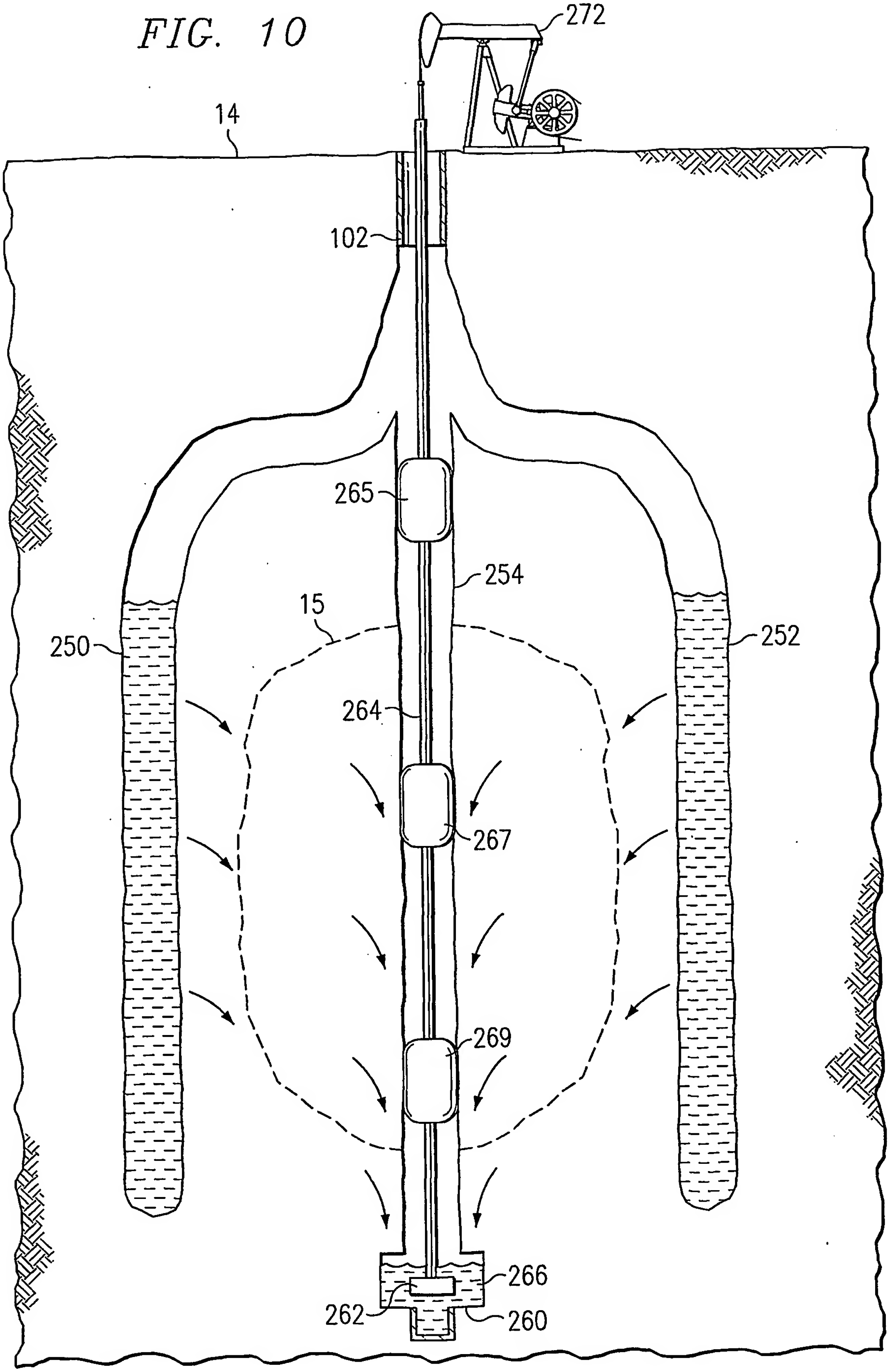


FIG. 9B

FIG. 10



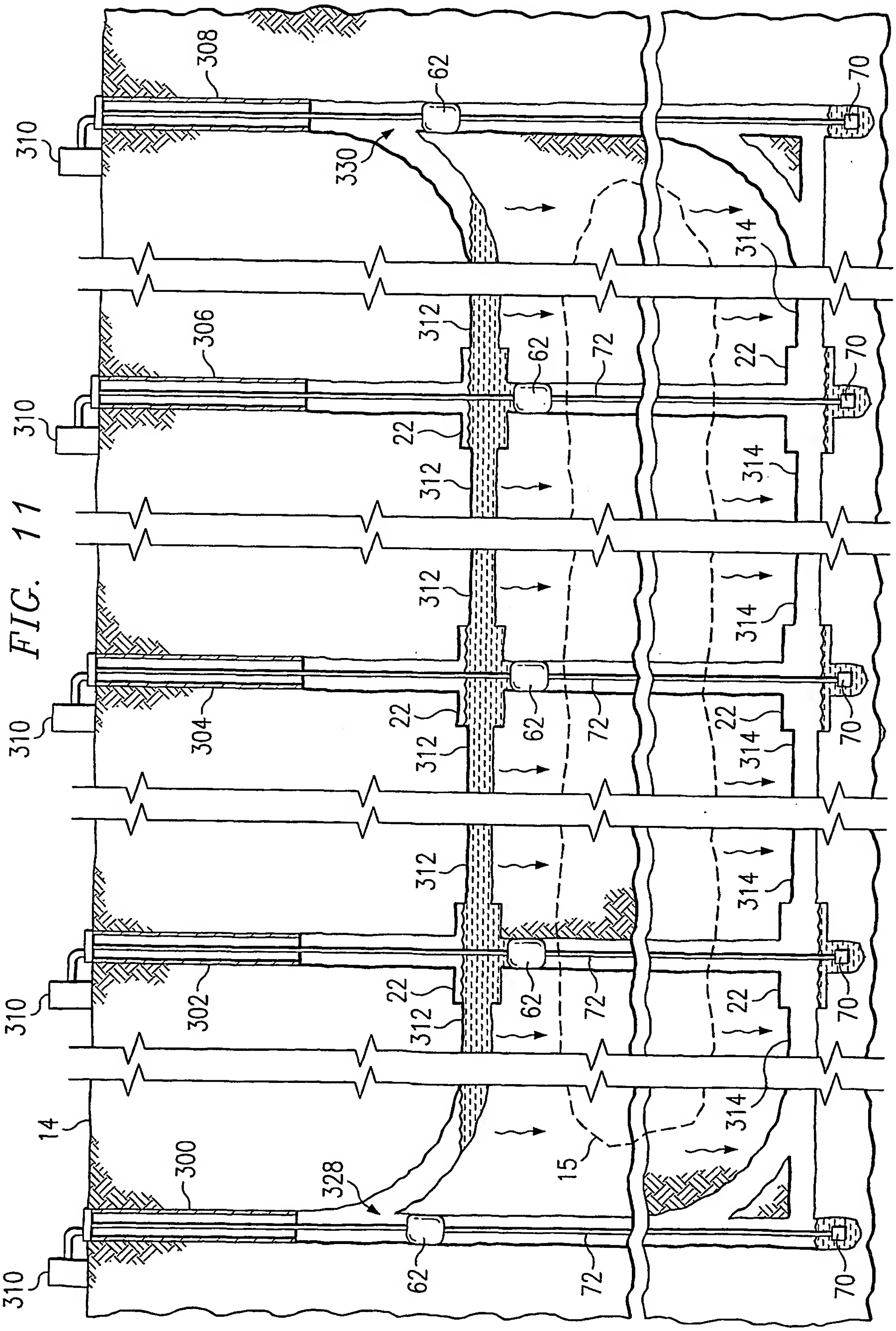
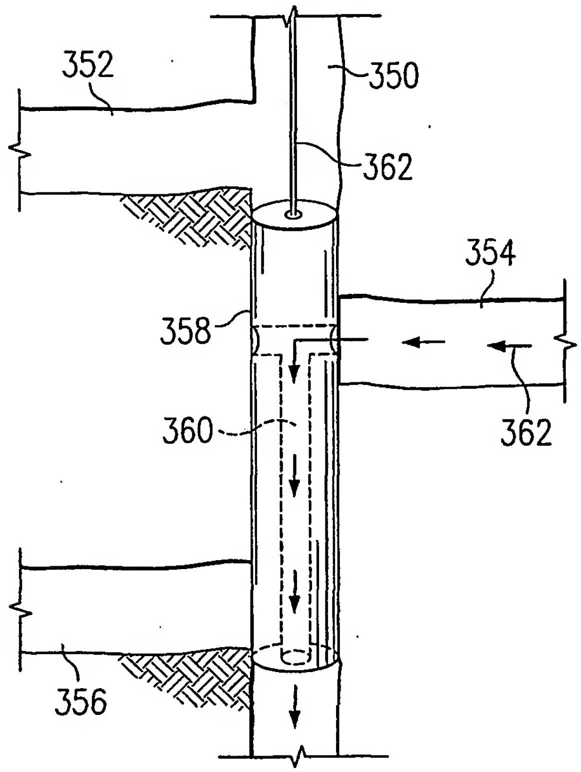


FIG. 11

FIG. 12



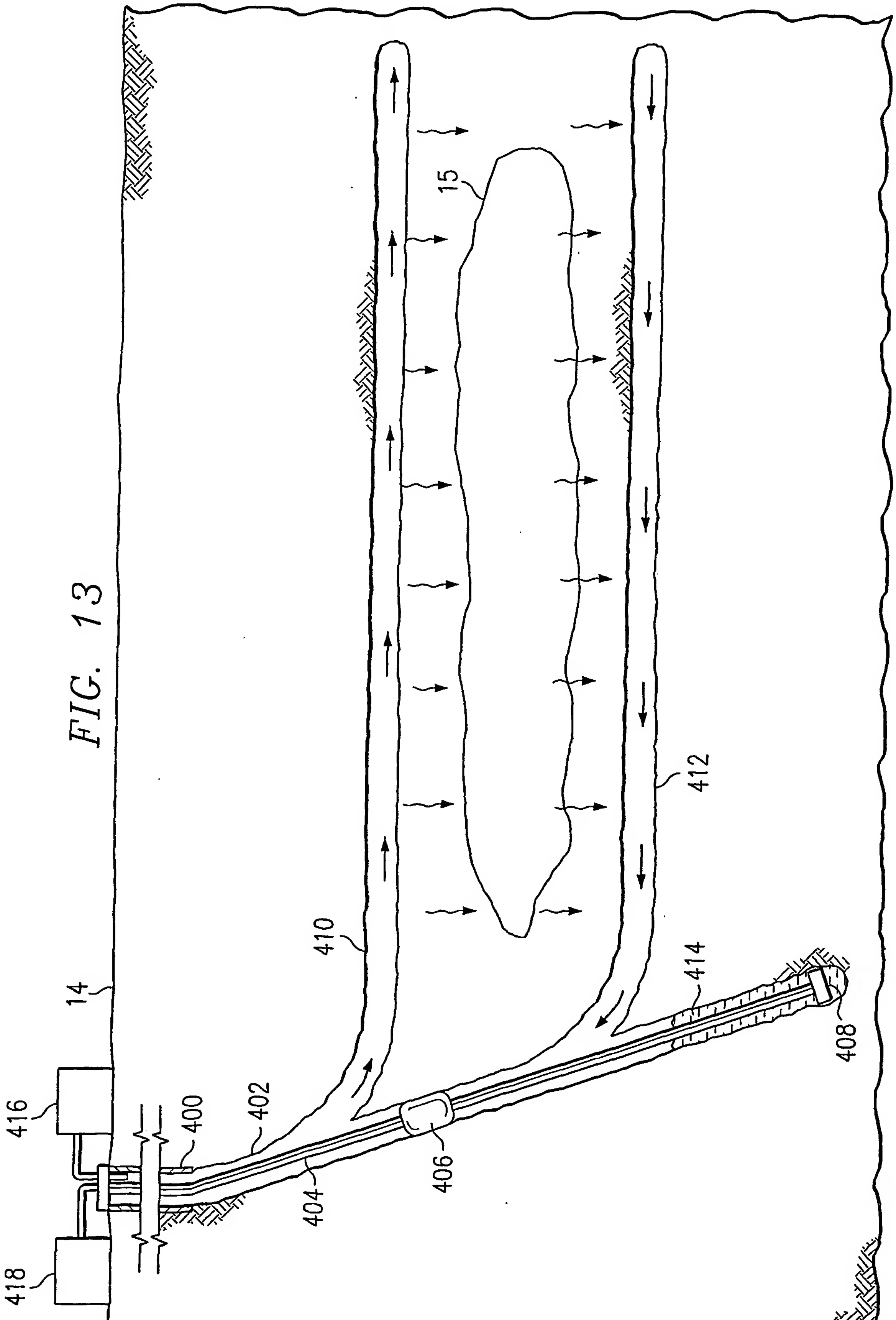
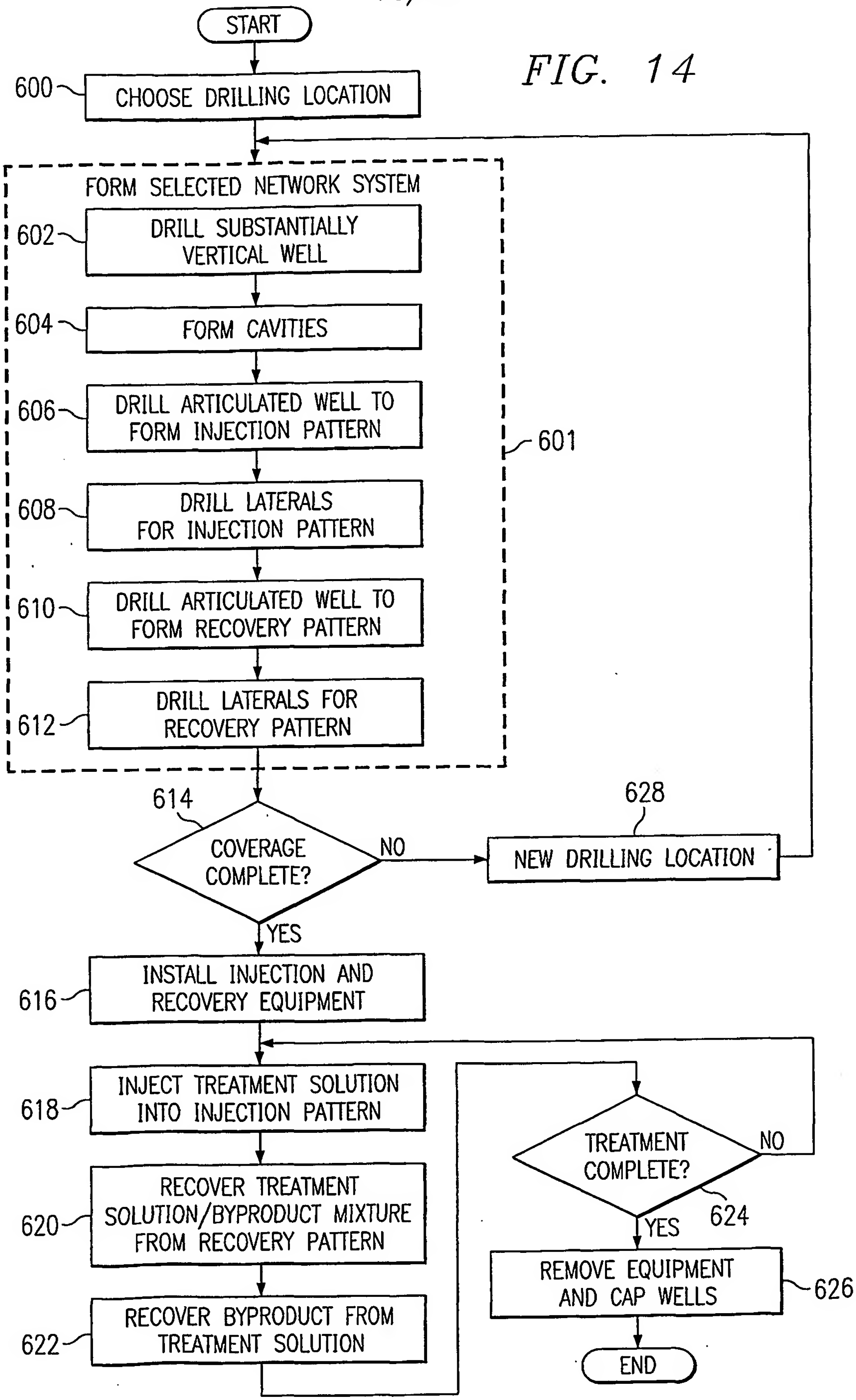


FIG. 13

FIG. 14


START
600
CHOOSE DRILLING LOCATION
FORM SELECTED NETWORK SYSTEM
602
DRILL SUBSTANTIALLY VERTICAL WELL
604
FORM CAVITIES
606
DRILL ARTICULATED WELL TO FORM INJECTION PATTERN
608
DRILL LATERALS FOR INJECTION PATTERN
610
DRILL ARTICULATED WELL TO FORM RECOVERY PATTERN
612
DRILL LATERALS FOR RECOVERY PATTERN
601
614
COVERAGE COMPLETE?
NO
628
NEW DRILLING LOCATION
YES
616
INSTALL INJECTION AND RECOVERY EQUIPMENT
618
INJECT TREATMENT SOLUTION INTO INJECTION PATTERN
620
RECOVER TREATMENT SOLUTION/BYPRODUCT MIXTURE FROM RECOVERY PATTERN
622
RECOVER BYPRODUCT FROM TREATMENT SOLUTION
TREATMENT COMPLETE?
NO
624
YES
626
REMOVE EQUIPMENT AND CAP WELLS
END

PCT/US 03/13954

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 E21B43/30

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 463 988 A (WORSHAM RICHARD E ET AL) 7 August 1984 (1984-08-07)	1,2, 5-12, 15-20
Y	figures 1-10	3,4,13, 14,21-25
Y	US 6 357 523 B1 (ZUPANICK JOSEPH A) 19 March 2002 (2002-03-19) column 5, line 1-44	3,4,13, 14,21-25
A	US 4 020 901 A (PISIO PETER ET AL) 3 May 1977 (1977-05-03) figure 3	6,16

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 August 2003	01/09/2003

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	van Berlo, A

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